AD-A134 918 LONG LIFE ENGINE DISKS FROM RSR (RAPID SOLIDIFICATION RATE) POWDER(U) GENERAL ELECTRIC CO CINCINNATI OH AIRCRAFT ENGINE BUSINESS GROUP R H VAN STONE NOV 78 1/1

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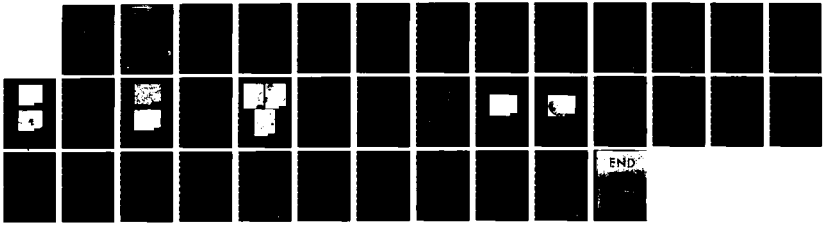

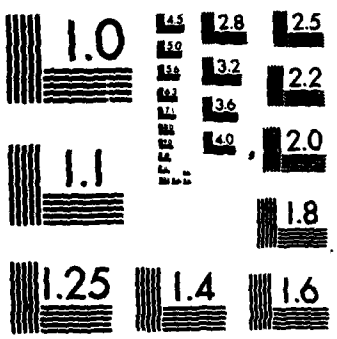

LONG LIFE ENGINE DISKS FROM RSR POWDER

R. H. Van Stone
General Electric Company
Aircraft Engine Group
Evendale, Ohio 45215

November 1978
Report for Period July 12, 1978 through October 31, 1978

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Sponsored by
Defense Advanced Research Projects Agency

Prepared for
Air Force Materials Laboratories
Wright-Patterson AFB, Ohio 45433

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A134918	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) LONG LIFE ENGINE DISKS FROM RSR POWDER		5. TYPE OF REPORT & PERIOD COVERED Technical Report July 12, 1978 - Oct. 31, 1978
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R. H. Van Stone		8. CONTRACT OR GRANT NUMBER(s) F33615-76-C-5100
9. PERFORMING ORGANIZATION NAME AND ADDRESS General Electric Co. Aircraft Engine Group Cincinnati, Ohio 45215		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced-Research Projects Agency 1400 Wilson Boulevard Arlington, Virginia 22209 (Dr. E. C. van Reuth)		12. REPORT DATE Nov. 1978
		13. NUMBER OF PAGES 26
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Air Force Materials Laboratories Wright-Patterson Air Force Base, Ohio 45433 (Mr. A. Adair)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release, Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Superalloys, Powder Metallurgy, Rapid Solidification, Turbine Disks, Solidification Microstructures

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report summarizes the work performed during the period from July 12, 1978 through October 31, 1978, on a DARPA-sponsored program to improve the elevated temperature low cycle fatigue (LCF) properties of nickel-base superalloys disk materials manufactured using rapid solidification rate (RSR) powder metallurgy techniques. The work during this quarter emphasized argon-atomization of Rene' 95 powder and characterization of its microstructure.

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20. ABSTRACT (Continued)

It has been shown that the dendrite arm spacing (DAS) particle size relationship of argon atomized Rene' 95 powder is equivalent to IN 100 powder, manufactured using the rotating disk, helium atomization method. Based on this observation -140 mesh (105 microns or 4.1 mils) has been selected for evaluation as RSR powder. A hot isostatic press (HIP) and heat treatment study to optimize LCF lives of Rene' 95, has been initiated in conjunction with the Crucible Materials Research Center. The manufacutre of small, prototype disks have been initiated at the Kelsey-Hayes Company. These disks will be used to qualify Kelsey-Hayes as a powder production source for this investigation.

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FOREWORD

This first Interim Technical Report describes the technical effort performed under Contract F33615-78-C-5100 from July 12, 1978 through October 31, 1978.

This contract is being performed for the Defense Advanced Research Projects Agency (DARPA) and is being performed under the technical direction of Mr. A. M. Adair of the Metals and Ceramic Division of the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

The program is being conducted by the Material and Process Technology Laboratories of the General Electric Company, Cincinnati, Ohio. At General Electric, the program is under the direction of Mr. E. J. Kerzicnik, Program Manager, and Dr. J. L. Bartos, Technical Program Manager with Dr. R. H. VanStone serving as the Principal Investigator. Major Subcontractors are Crucible Materials Research Center, Crucible Division of Colt Industries, Pittsburgh, Pa., and the Powder Consolidation Division of the Kelsey-Hayes Company, Brighton, Michigan. The Program Manager for Crucible is Mr. J. H. Moll and Principal Investigator is Mr. Frank Rizzo. The Program Manager for Kelsey-Hayes is Mr. D. M. Weaver and the Principal Investigator is Mr. T. Egerer. Professor J. F. Radavich of Purdue University and Professor S. D. Antolovich of the University of Cincinnati are Consultants on this program.

The primary objective of this program is to develop two As-HIP powder metallurgy nickel-base superalloy composition/process combinations having twice the low cycle fatigue (LCF) lives of the 650C (1200F) alloy Rene' 95 and the 760C (1400F) allow AF 115. These developments will attempt to take full advantage of the fine microstructure and segregation characteristics of rapid solidification rate (RSR) powder. Also included in the program is a design study and evaluation of prototype disks to assess the impact of improved LCF on disk life.

INTRODUCTION

The continued demand for higher performance aircraft gas turbine engines with longer operating lives and improved reliability has encouraged the development of new turbine disk alloys which are capable of operating at higher stresses and higher temperatures. Historically, disk alloys have been developed to improve tensile properties, creep strength, and rupture lives. A major step forward to increase temperature capability was the development of nickel-base superalloys which are manufactured by powder metallurgy (PM) methods. This technology provides improved material utilization and avoids mechanical property variations resulting from segregation and difficult forging operations.

The goal of the current program is to develop PM composition/process combinations with improved low cycle fatigue (LCF) lives over current PM superalloys. This investigation will take full advantages of the refined microstructures of rapid solidification rate (RSR) powder. The rapid solidification rate will provide material free of macrosegregation and thus permit the development of alloys which could not be manufactured using conventional casting and forging processes.

The specific goals include development of a 1200F alloy/process combination with twice the LCF lives of PM Rene' 95 and a similar improvement for a 1400F alloy over AF 115.

PROGRAM PLAN AND ORGANIZATION

This investigation has four basic components:

1. Develop a 1200F alloy/process with improved LCF lives
2. Develop a 1400F alloy/process with improved LCF lives
3. Design studies to optimize disk design with respect to LCF properties
4. Component manufacture and evaluation

The powder and compacts for the 1200F alloy development are being manufactured and fabricated at the Crucible Materials Research Center (CMRC). The powder and compacts for the 1400F alloy development are being produced at the Powder Consolidation Division of the Kelsey-Hayes Company.

The investigation is divided into four phases. Each phase involves both 1200F and 1400F alloy/process development, except for Phase I which will only consider Rene' 95. These Phases are listed below:

Phase I - Powder Production Source Selection and Qualification

Phase II - Process Development

Phase III - Alloy Development

Phase IV - Design Studies

Phase I involves selection and qualification of the powder manufacturers, based on acceptable LCF properties of powder metallurgy Rene' 95. Phase II investigates the influence of inert gas atomization processing, hot isostatic press (HIP) parameters, and heat treatment on the microstructure and LCF lives of the baseline alloys - Rene' 95 and AF 115. Using the results of Phase II, new alloys will be designed, manufactured, and evaluated to improve LCF lives in Phase III. The Phase IV design study will evaluate the role of disk design on cyclic disk life.

1200F ALLOY/PROCESS DEVELOPMENT

Phase I - Powder Production Source Selection and Qualification

Crucible Materials Research Center (CMRC) has been selected as the powder source for the development of the 1200F alloy/process combination. Crucible is considered to be a qualified powder source due to the extensive experience of GE with CMRC PM superalloys and the high level of their baseline data. CMRC has been approved by DARPA as a powder source and has initiated work on Phase II and Phase III.

Phase II - Process Development

- Powder Production and Characterization

Two heats of argon-atomized Rene' 95 powder were produced in the 500 pound research atomizer at CMRC. The compositions of heats 516-285 and 516-302 given in Table I are well within the Rene' 95 specification.

The intent of the powder characterization portion of this investigation is to determine the powder size required to produce rapid solidification rate (RSR) powder using commercial argon-atomized powder sources. Both heats of Rene'95 were studied using optical metallography, scanning electron microscopy (SEM), extraction techniques, and x-ray diffraction. This work was conducted jointly by GE and Professor J. F. Radavich of Purdue University. A small portion of each heat was screened to the mesh sizes given in Table II.

The morphology of powder particles was studied using SEM. The powders were spherical for all mesh sizes. In the -60 +100 mesh size samples, some cigar-shaped powder particles were also observed. There were two major types of surface features - small spherical satellite particles attached to larger particles and splat layers partially or totally covering a powder particle. Figure 1 shows SEM micrographs of the -200 +230 mesh size cut from powder heat 516-302. Figure 1a illustrates the spherical nature of argon-atomized powder. Figure 1b shows a splat layer around a particle and small satellites attached to the main particle. The dendritic solidification microstructure can easily be seen on the surface of the particles. The white region indicated with the arrow in Figure 1b was identified as an alumina (Al_2O_3) particle using x-ray energy dispersive analysis in the SEM. This 25 micron (1 mil) inclusion was the only defect observed in the SEM study of these powders. From the observations of the various size classes, it was concluded that as the powder size decreased, the frequency of both satellites and splat layers diminished.

TABLE I

CHEMICAL ANALYSES OF CMRC RENE' 95 POWDER HEATS

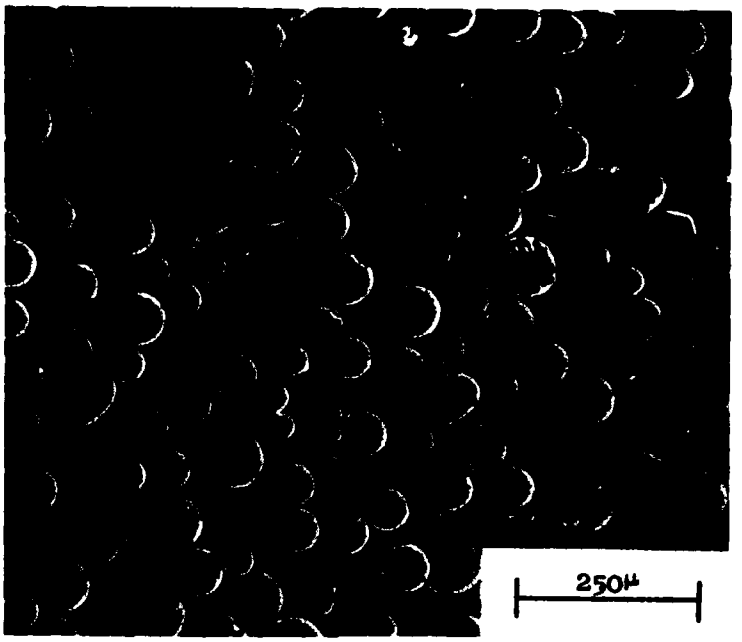
(Weight Percent)

Element	Specification	Heat 516-285	Heat 516-302
Cr	12.0 - 14.0	12.93	12.97
Co	7.0 - 9.0	8.26	8
Al	3.3 - 3.7	3.34	0
Ti	2.3 - 2.7	2.60	3
Mo	3.3 - 3.7	3.55	
W	3.3 - 3.7	3.42	3.45
Cb	3.3 - 3.7	3.44	3.47
Zr	0.03 - 0.07	0.04	0.04
B	0.006 - 0.015	0.008	0.009
C	0.04 - 0.09	0.059	0.059
0_2	0.01 max	0.0050	0.0065
S	0.015 max	0.002	0.003

TABLE II

MESH SIZES USED IN POWDER CHARACTERIZATION

U. S. STANDARD MESH SIZE RANGE	SIZE RANGE (Microns)	SIZE RANGE (Mils)
-60 +100	149-250	5.9-9.8
-100 +140	105-149	4.1-5.9
-140 +170	88-105	3.5-4.1
-170 +200	74-88	2.9-3.5
-200 +230	62-74	2.4-2.9
-230 +270	53-62	2.1-2.4
-270 +325	44-53	1.7-2.1
-325 +400	37-44	1.5-1.7
-400	less than 37	less than 1.5



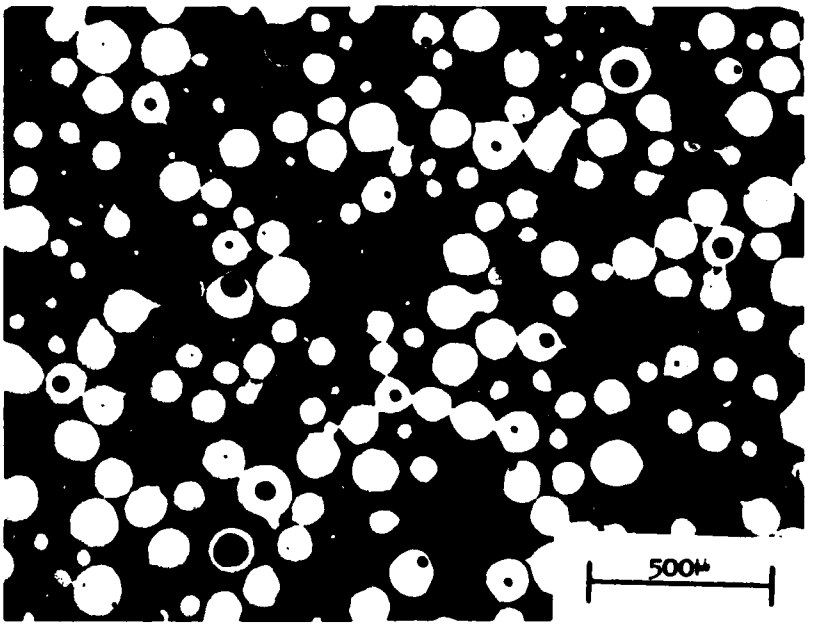
(a)

(b)

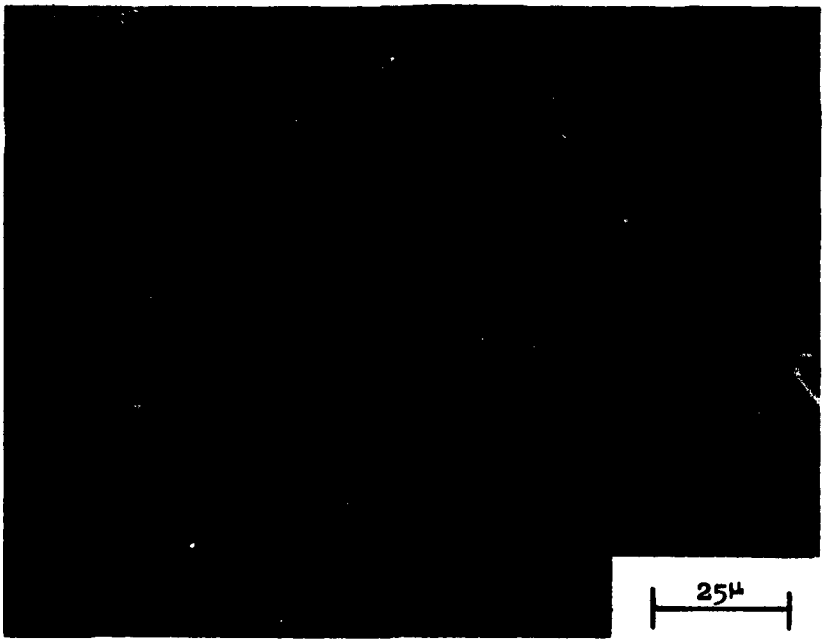
Figure 1. SEM Micrographs Showing Rene' 95 Powder from the -200 + 230 Mesh Size Cut of Heat 516 - 302. The Arrow in Figure 1B Points to an Attached Alumina Inclusion.

The internal microstructure of the powder particles was studied using metallographic sections of powder mounted in epoxy and SEM analysis of powder particles which were prepared using an electrolytic extraction procedure (1). Using metallographic sectioning techniques on unetched specimens, two types of internal porosity were observed - large internal cavities or hollows and small microshrink porosity in interdentritic regions. Examples of porosity and microshrink are shown in Figures 2a and 2b respectively. The frequency and size of porosity diminish with decreasing powder size. Figure 3 is a plot of the fraction of particles which exhibit porosity when viewed at a magnification of 100X and the maximum pore size as a function of powder size for powder heat 516-285. The fraction of porous particles varies in an almost linear fashion with powder size; however, the maximum size of porosity is almost a step function reaching a size of 13.6 microns (0.5 mils) in powders smaller than 140 mesh (105 microns or 4.1 mils). This is caused by a large decrease in the frequency of hollows below this powder size. The 13.6 micron porosity is almost entirely microshrink cavities.

The internal microstructure of the Rene' 95 powder was primarily dendritic. This was revealed with both metallographic cross sections of etched specimens and examinations of powder after electrolytic extraction. Figure 4 shows optical micrographs of powder heat 516-302 from the following mesh size cuts: -60 +100; -200 +230; and -400. These micrographs show a substantial decrease in dendrite arm spacing (DAS) with decreasing powder size. Similar results have been previously observed (2, 3, 4). One purpose of this investigation is to compare the influence of powder manufacturing process on the solidification rate (or fineness of microstructure) and the resultant low cycle fatigue (LCF) properties. To compare the solidification rates between different processes, the DAS-powder size relationship will be compared. It is well established that DAS decreases with increasing solidification rate (decreased solidification time) (5). A major difficulty in defining solidification rate is that every alloy have a specific DAS-solidification rate relationship which should not be extended beyond the solidification rate range where data has been determined experimentally. Such relationships have been established for very few alloys. Comparisons between relationships show that, for a given value of DAS, solidification rates can vary by as much as an order of magnitude. Recent studies of various compositions of nickel-base superalloys atomized using a spinning disk in a helium environment have shown that very small changes in composition, most noteable intersitial level, can significantly alter the DAS obtained using identical atomization conditions (6). Based on these difficulties, the measure of solidification rate to be used in this investigation will be the DAS rather than an inferred or calculated solidification rate. It is believed that the DAS is more appropriate to describe material response than a solidification rate because DAS better describes the scale of the segregation pattern or diffusion distance and the fineness of the microstructure.



(a)



(b)

Figure 2: Optical Micrographs Showing Examples of (a) Hollow Particles and (b) Microshrink Porosity in Unetched Rene' 95.

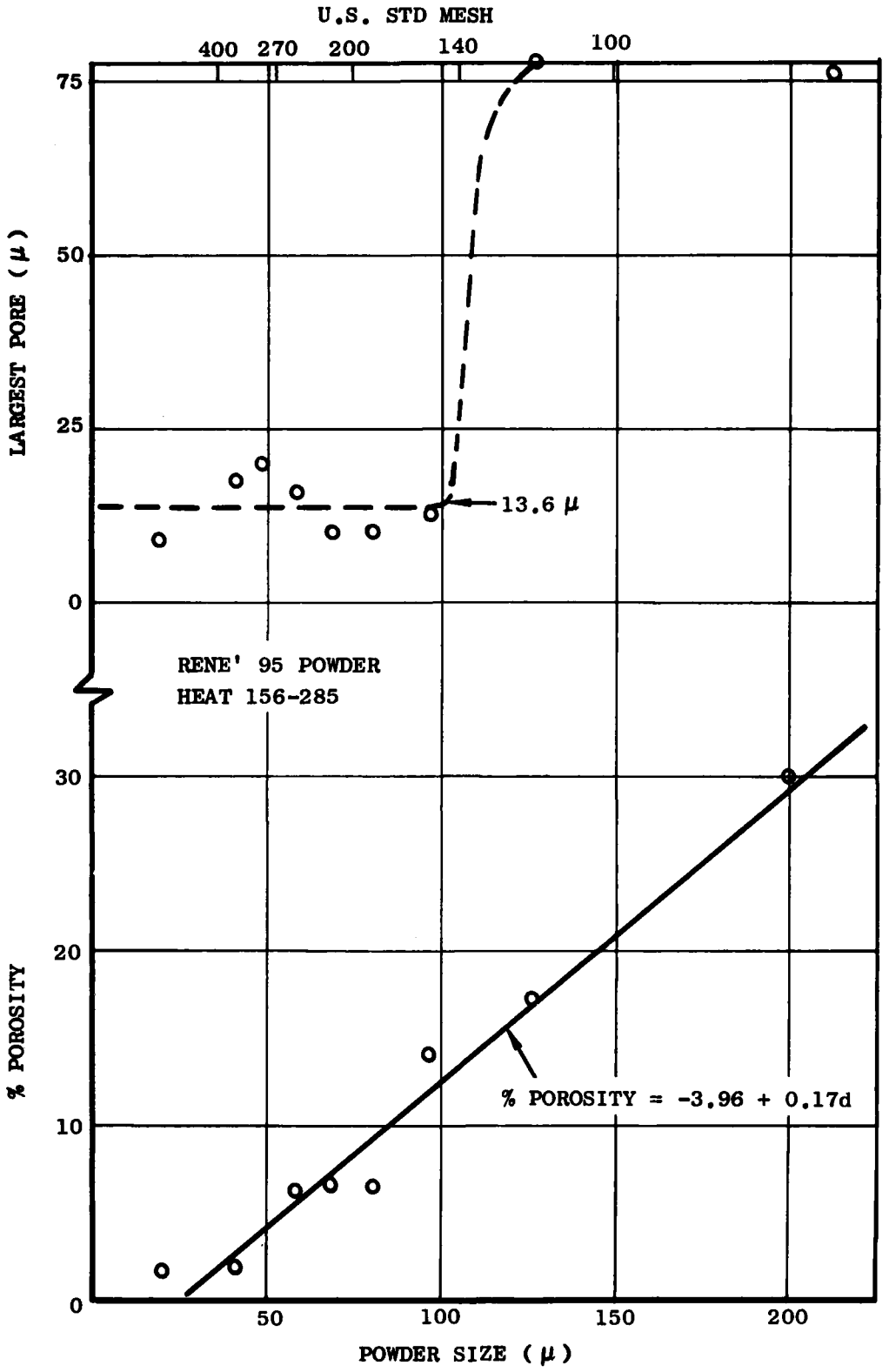


Figure 3. Variation of Fraction of Porous Particles and Maximum Pore Size as a Function of Powder Size in Rene' 95.

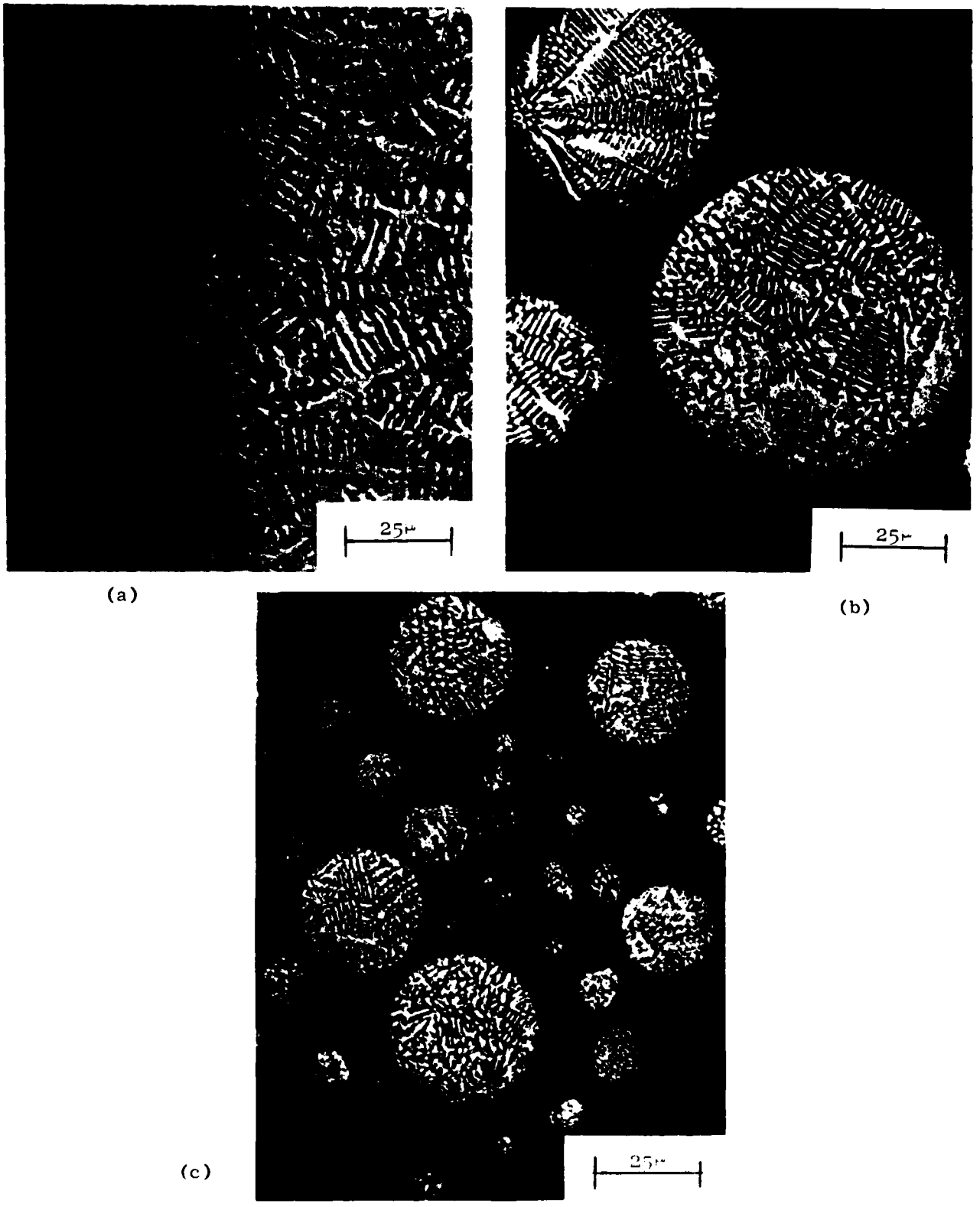


Figure 4. Optical Micrograph of Rene' 95 Powder Heat 516-302 from the Following Mesh Size Cuts: (a) -60 +100, (b) -200 +230, (c) -400.

The values of DAS were determined for Rene' 95 powder heat 516-302 by Professor J. F. Radavich of Purdue University. The DAS was measured from SEM micrographs of polished and etched cross-sections of powder particles. The technique used to measure DAS is similar to that described by Glickstein, et al. (7). The DAS data for argon-atomized Rene' 95 are given in Table III. These data are plotted in Figure 5 along with the DAS calculated from the cooling rates reported by Cox, et al. (4), to be typical of the rotating disk atomized IN 100. Two values for each particle size of IN 100 are shown based on the two DAS-solidification rate relationships (2, 8) used in that investigation. The line shown in Figure 5 is a linear least square regression of the Rene' 95 data listed in Table III. The equation has the following form:

$$DAS = 0.32 + 0.015\ d \qquad \text{Equation (1)}$$

where the units of both DAS and d, the powder size, are given in microns.

The IN 100 data falls very close to this relationship for Rene' 95. This should not be surprising because Joly and Mehrabian (2) concluded from their study of several atomization processes that the local average cooling rate inferred from DAS is primarily controlled by the powder size and to a lesser extent by the cooling medium. Their result was based on powder sizes in excess of 1000 microns (39.4 mils) while the results of the current investigation are typically less than 200 microns (7.9 mils). Results on superalloy powder suggest that the conclusions of Joly and Mehrabian (2) can be extended to the smaller powder sizes.

During the remainder of this investigation, a more extensive evaluation of the DAS-particle size relationship will be made. The variations to be studied will include powder source, inert gas atomizing medium, and alloy composition.

It has been reported (4) that the rotating disk atomizing process is capable of producing relatively small fractions of a non-dendritic microstructure in fine mesh powders which has become known as a "microcrystalline" structure (4). Metallographic observation of the Rene' 95 powders revealed some particles with a non-dendritic structure. Figure 6 shown an optical micrograph of the -230 +270 mesh size fraction of heat 516-283 with several particles, including one labeled A, which appear to have a non-dendritic microstructure. It was fairly easy to find such particles, but it is highly probable that this microstructure is a result of the plane of the metallographic section. The reason for this conclusion is that particles which had received the electrolytic extraction procedure always appeared to be dendritic. Figure 7 shows such a -400 mesh powder particle from heat 516-302. The extraction technique removed material from the interdendritic regions which was subsequently analyzed using x-ray diffraction. In all powders, MC carbides and Laves phase were identified. The lattice parameter of MC was 4.398 Å for the large powder and was 4.388 Å for the finer powder. The transition occured in the vicinity of 140 mesh size (105). The change in lattice parameter indicates a vaiation in MC composition. No borides were identified in the extracted residues.

TABLE III

DENDRITE ARM SPACINGS (DAS) FOR RENE' 95 POWDER PRODUCED BY CMRC

Particle Size (Microns)	DAS (Microns)
140 - 170	3.0
120 - 160	1.5 - 2.5
30 - 40	1.0
14 - 22	0.5

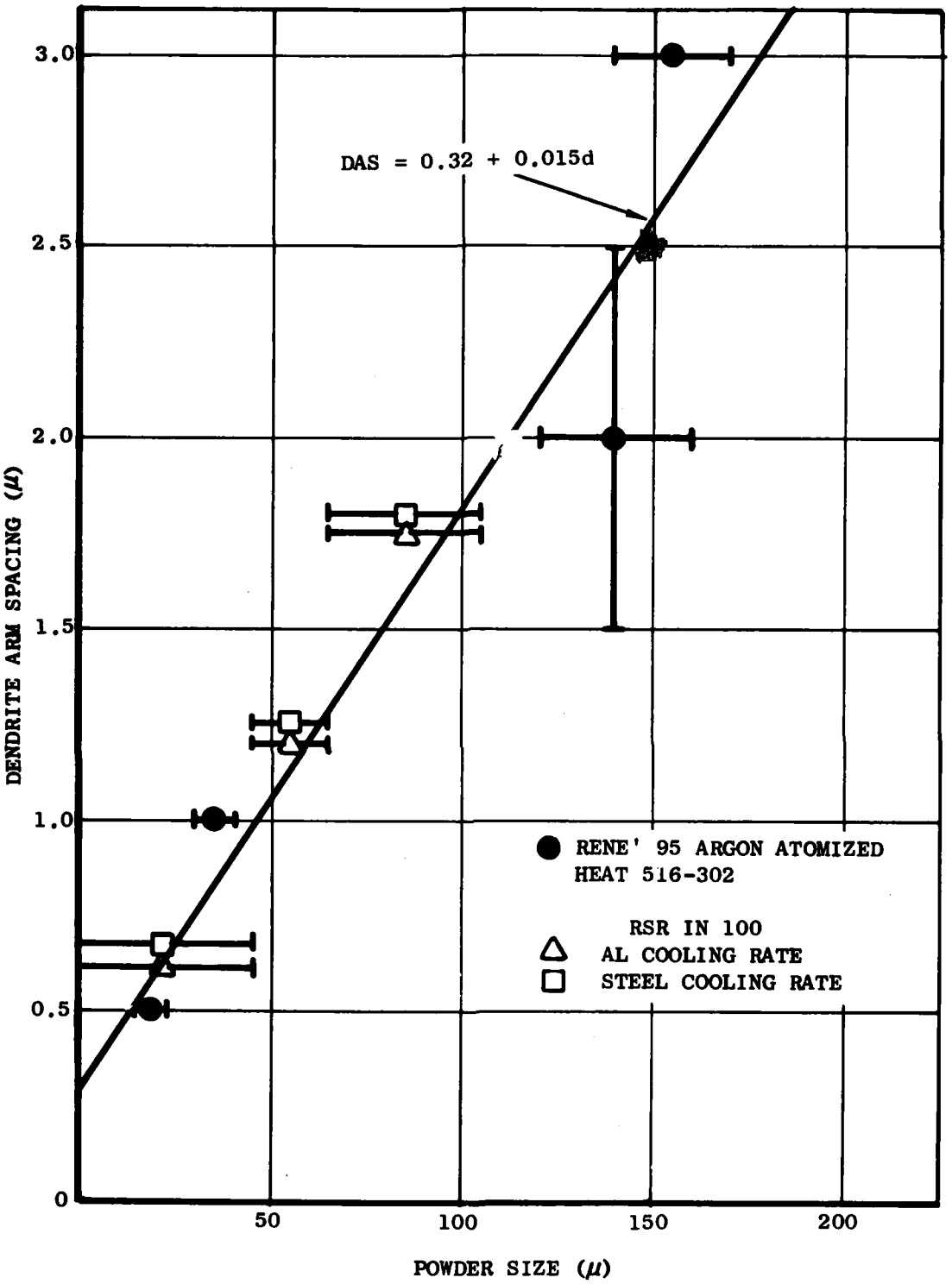


Figure 5. Variation of Dendrite Arm Spacing with Powder Size for Rene' 95 and IN 100

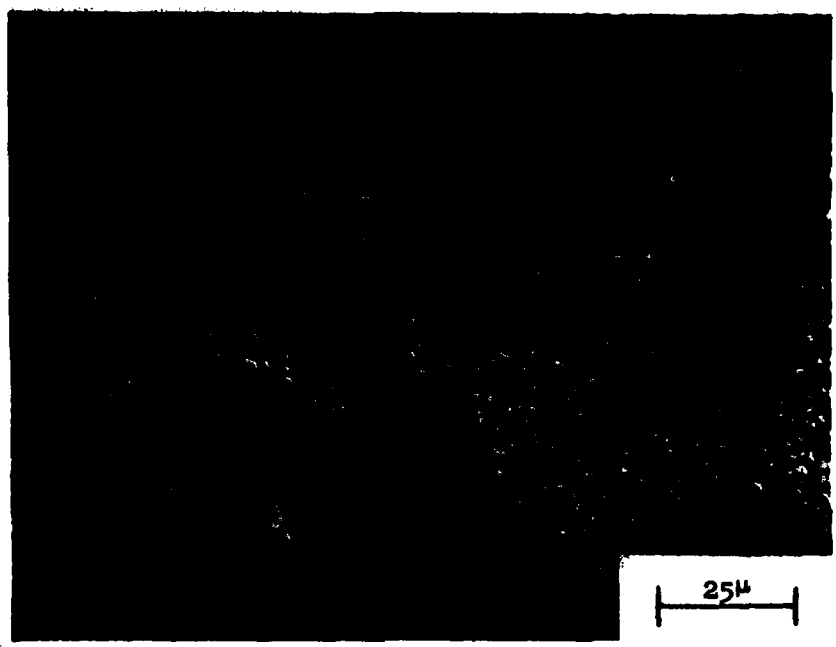


Figure 6. Optical Micrograph of Polished and Etched Rene' 95 Particles. The Particle Labled A Appears to Have a Non-Dendritic Microstructure.

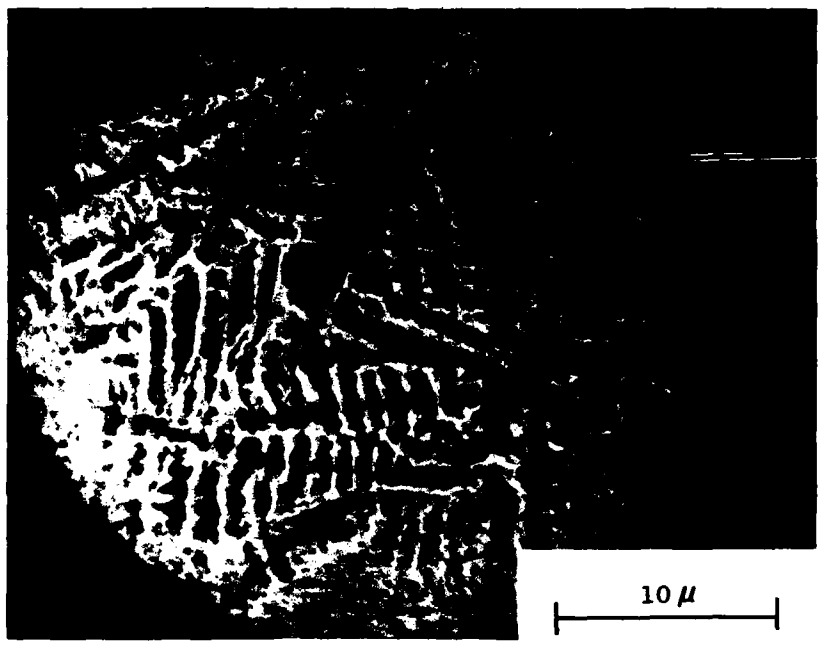


Figure 7. SEM Micrograph of a -400 Mesh Size Powder Particle of Rene' 95 Following Electrolytic Extraction

The purpose of characterizing the microstructure of the argon atomized Rene' 95 powder is to determine the size of powder required to assure utilization of RSR powder. It has been demonstrated that CMRC argon atomized powder has the same dendrite arm spacing for a given powder size as the rotating disk RSR powder. The powder size selected for this investigation is -140 mesh (smaller than 105 microns or 4.1 mils). The DAS of this mesh fraction is equivalent to that of powders used in other RSR investigations (6), where cooling votes of 10^5-10^6 °C/sec were calculated. The selection of this size range maximized the yield while largely eliminating hollow particles and variations in carbide composition previously discussed. To assess the influence of solidification rate on LCF, it is planned to evaluate the LCF behavior both -140 and -270 mesh (53 microns or 2.1 micron) powder in the compaction parameter refinement portion of this phase.

Based on this decision, powder heats 516-285 and 516-302 were processed through a magnetic separation cycle and screened to -140 mesh size. The -140 mesh product of these two heats was then vacuum blended together to form Master Blend MB066. Table IV contains the screen analyses of both heats after screening to 150 mesh. The cumulative distributions for these argon atomized heats of Rene' 95 and the rotating disk atomized IN 100 (4) are shown in Figure 8. This illustrates that these Rene' 95 heats have many more fine particles than the rotating disk atomized IN 100. A weighted DAS valve can be calculated using the following equation:

$$\overline{DAS} = \sum_i W_i (DAS)_i \qquad \text{Equation (2)}$$

where

$\overline{DAS}$ = weighted DAS

W_i = fraction of a given powder size

$(DAS)_i$ = DAS for a given powder size

The values of W_i for Rene' 95 are the averages of those given in Table IV. The values of (DAS) were calculated using equation 1 and the maximum value of powder size for a given class size. Table V lists $\overline{DAS}$ as a function of mesh size for the Rene' 95 and IN 100 size distribution. At larger particle sizes, the IN 100 has a $\overline{DAS}$ over 30% greater than the Rene' 95 distributions. At the finer particle size, the $\overline{DAS}$ values are very similar. If a higher solidification rate is beneficial to properties, these data suggest that argon atomized powder has an advantage over the rotating disk atomized powder at a -150 mesh size, due to the variations in size distribution.

TABLE IV

SCREEN ANALYSES OF CMRC RENE' 95 POWDER HEATS

(Weight Percent)

U. S. Standard Mesh Size	Size Range (Microns)*	Heat 516-285	Heat 516-302
-150 +170	88-105	4.2	8.8
-170 +200	74-88	7.4	12.6
-200 +230	62-74	8.4	10.3
-230 +270	53-62	7.7	9.0
-270 +325	44-53	32.0	19.7
-325 +400	37-44	3.7	8.5
-400	Less than 37	36.6	31.1

*Micron = .039 Mils

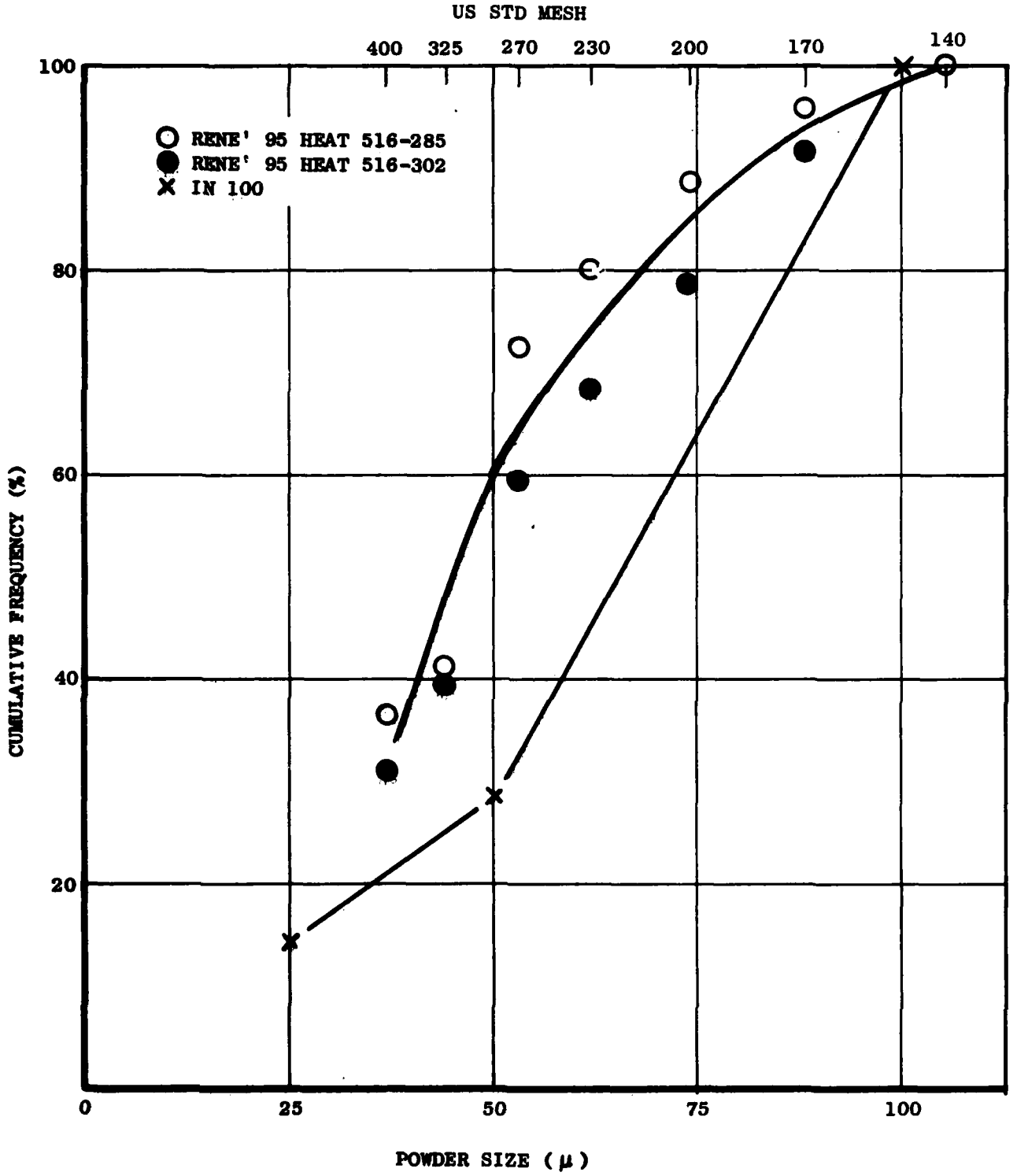


Figure 8. Comparison of Cumulative Powder Size Distribution for Argon Atomized Rene' 95 and Rotating Disk Atomized in 100.

TABLE V

WEIGHTED DENDRITE ARM SPACING ($\overline{DAS}$) OF SUPERALLOY POWDER

U. S. Standard Mesh Size	Size (Microns)	Powder (Mils)	Rene' 95 $\overline{DAS}$ (Microns)	IN 100 $\overline{DAS}$ (Microns)
-140	105	4.1	1.172	1.551
-270	53	2.1	0.979	0.886

- Compaction Parameter Refinement

The objective of this portion of the program is to investigate hot isostatic pressing (HIP) and heat treatment parameters for As-HIP Rene' 95 product. The evaluation criteria for this study includes microstructure, gas analyses, density, TIP and tensile testing at both room temperature and 1000F. Six 2-inch diameter stainless steel containers 15-inches long were prepared and welded according to standard procedures. The cans were loaded with -150 mesh Rene' 95 powder from MB066, outgassed, sealed and shipped to Battelle-Columbus Laboratories for HIP compaction.

The HIP parameters for this first series of six cans are contained in Table VI. These HIP parameters were selected to evaluate a wide range of conditions including those above the γ' solvus temperature as well as temperatures substantially below the standard Rene' 95 HIP temperature aimed at retaining the fine microstructure of the -140 mesh powders. During the next quarter, these compacts will be HIP'ed according to the conditions listed in Table VI and cut into 3 sections. Each section will be heat treated using parameters selected based on the As-HIP'ed microstructure. Following heat treatment, the material will be evaluated according to the criteria listed above.

Phase III - Alloy Development

The objective of this task is to produce two series of ten 1200F alloy variations and evaluate them to determine the effect of composition on low cycle fatigue (LCF) properties.

During this quarter, the composition of the 1200F Series I alloys were designed using General Electric's superalloy design computer program. These programs predict the carbide, boride, γ, and γ' volume fraction and composition from the bulk alloy compositions. These alloys were designed to provide very large variation in γ' volume fraction, γ' composition, and solid solution strengthening elements. The compositions of these alloys are listed in Table VII. Figure 9 shows a plot of the atomic percent of the sum of the solid solution strengthening elements Mo, W, and Re against the computer predicted γ' volume (atom) fraction for Rene' 95, AF 115, IN 100, and the 1200F Series I alloys. Alloys 1 through 7 were designed to have one major change from alloy to alloy while the remaining three were to examine synergistic effects between those variations. The predicted γ' content of these alloys varies from 31 to 68 percent while the predicted γ/γ' mismatch cover a range from 0.37 to 1.14 percent. This wide range of microstructures were designed to determine which parts of the microstructure are most beneficial to improve LCF lives. This information will be used to assist in the design of the 1400F Series I and 1200F Series II alloys. During the next quarter, the 10 Series I alloys will be argon atomized.

TABLE VI

HIP PARAMETERS

HIP Cycle Code	Temperature (F)	Pressure (ksi)	Time (hr)
A	1800	15	7
B	1800	15 + 30*	7 + 3
C	1925	15	3
D	1925	15	7
E	2050	15	3
F	2175	15	3

*Cycle B will be held at 15 ksi for 7 hours then pressurized to 30 ksi and held for 3 more hours.

TABLE VII

1200° F SERIES I ALLOY COMPOSITIONS

(Weight Percent)

Element	1	2	3	4	5	6	7	8	9	10
Co	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Cr	13.0	13.0	13.0	13.0	13.0	13.0	18.0	16.0	10.0	13.0
Mo	3.5	3.5	3.5	3.5	3.5	0.5	3.5	1.0	1.0	2.5
W	3.5	3.5	3.5	3.5	3.5	3.5	3.5	1.0	1.0	5.5
Al	3.5	1.75	1.75	4.75	4.75	4.75	3.5	5.5	6.0	2.0
Ti	2.5	2.5	2.5	0.5	0.5	0.5	2.5	1.0	1.5	2.0
Ta	--	--	--	--	--	--	--	--	7.5	1.5
Cb	0.50	0.50	0.50	3.5	7.0	7.0	3.5	1.0	2.5	1.5
Zr	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Re	--	--	6.0	--	--	--	--	1.0	--	2.5
B	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Nd	--	--	--	--	--	--	0.01	--	--	--
Ni	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.

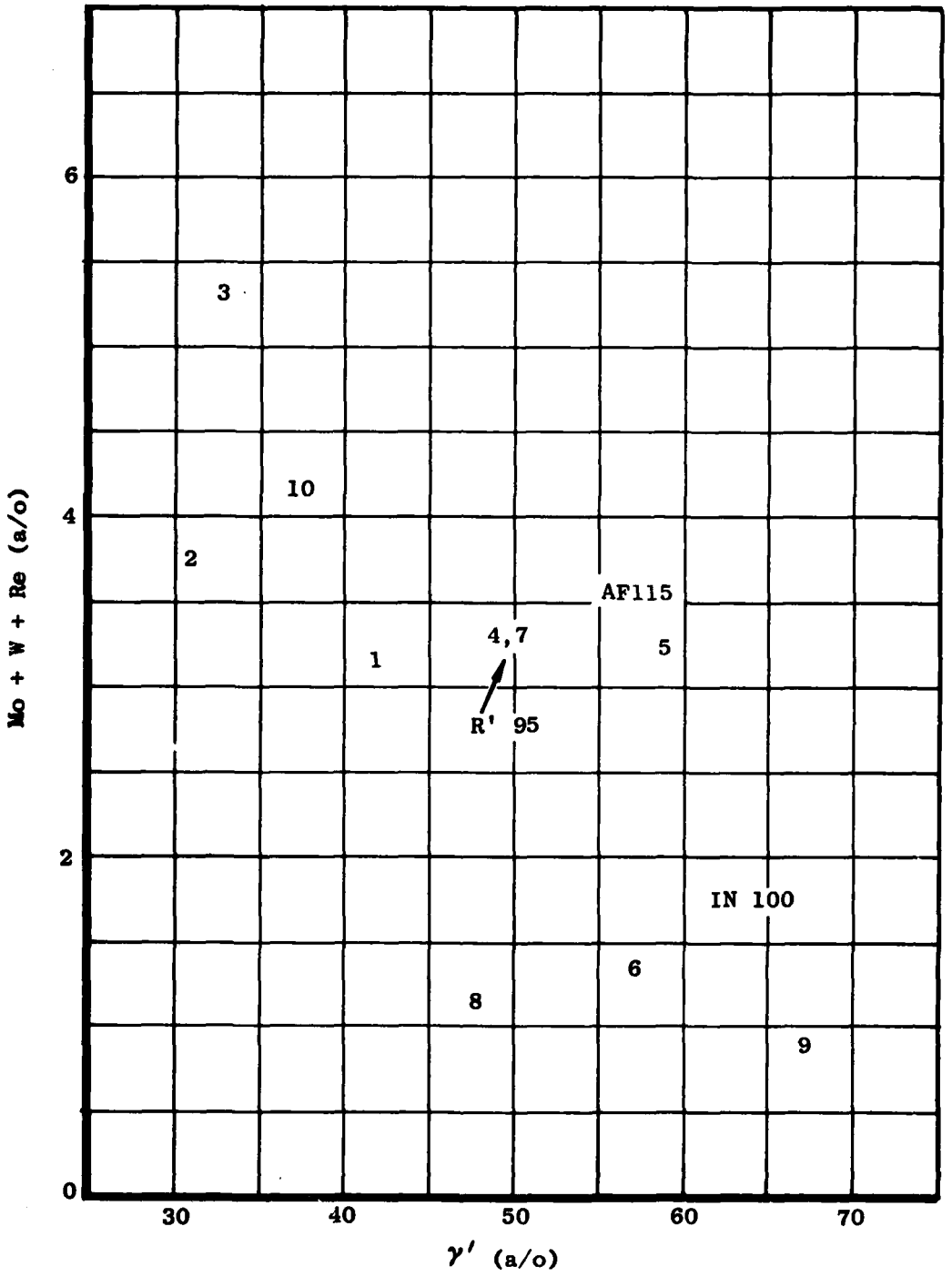


Figure 9. A Plot Showing the Amount of Solid Solution Strengthening Element and Computer Predicted for Rene' 95, AF 115, IN 100, and the 1200°F Series I Allots.

1400F ALLOY/ PROCESS DEVELOPMENT

Phase I - Powder Production Source Selection and Qualification

The Powder Consolidation Division of the Kelsey-Hayes Company has been selected as the powder source for the 1400F alloy/process combination. During this phase, the 1000F low cycle fatigue (LCF) lives and tensile properties of Rene' 95 will be evaluated and compared to the General Electric data base for Rene' 95. This powder source is required to be qualified prior to further participation in this program.

The powder manufacturing and consolidation processes used by Kelsey-Hayes have been described previously[10] and will not be reviewed here in detail. The product forms to be manufactured are small prototype disks approximately seven inches in diameter and two inches thick. Disks will be produced from powder in two argon-atomizated powder heats. The starting material for these powder heats included vacuum induction melted heats VF-126, VF-127, and VF-128 and powder revert stock. The chemical analyses of the heats and the Rene' 95 specification are listed in Table VIII. These heats are extremely uniform in composition and are within the specification.

Two powder heats (L-539 and L-540) were processed separately. Upon completion of atomization, the powder was hand screened through a 40 mesh sieve (420 microns or 16.5 mils). The -40 powder was then screened to a -140 mesh size (105 microns or 4.1 mils) in a sonic separator. The +140 mesh stock was used for revert stock in subsequent atomization cycles. The powder lots were jet classified[10] using argon gas. Besides screening of powder contaminants, the jet classifier was used to separate the powder at -270 mesh size (53 microns or 2.1 mils). The -140 +270 mesh powder was processed using electrostatic separation (ESS) in an inert atmosphere. Prior experience has shown that ESS of the fine -270 powder is a very time-consuming process due to the many cleaning operations of the equipment.

After ESS, the -140 +270 mesh powder was blended with the -270 mesh powder. The mesh size distributions of these heats after screening to a -140 mesh size are given in Table IX. Table X lists apparent density, tap density, flow rate, and oxygen content of the two powder lots.

The powder was stored in stainless steel containers under an inert gas environment. During the next quarter these two powder heats will be loaded into metal containers using the electrodynamic degassing process[10], HIP'ed and heat treated. The microstructure of the powder will also be characterized in manner similar to that completed in the 1200F alloy/process development portion of the program.

TABLE VIII

CHEMICAL ANALYSES OF RENE' 95 INGOTS

Element	Specification Minimum	Specification Minimum	Heat VF-126	Heat VF-127	Heat VF-128
Cr	12.0	14.0	13.4	13.5	13.5
Co	7.0	9.0	7.7	7.7	7.6
Al	3.30	3.70	3.47	3.45	3.44
Ti	2.30	2.70	2.4	2.4	2.4
Mo	3.30	3.70	3.5	3.5	3.68
W	3.30	3.70	3.5	3.4	3.4
Cb	3.30	3.70	3.6	3.5	3.4
Zr	0.03	0.07	0.04	0.05	0.04
B	0.006	0.015	0.012	0.012	0.012
C	0.04	0.09	0.049	0.049	0.048
O_2	---	0.01	0.0006	0.0004	0.0004
S	---	0.015	0.0016	0.0014	0.0012

TABLE IX

MESH SIZE DISTRIBUTION OF KELSEY-HAYES RENE' 95 POWDER HEATS

(Weight Percent)

U. S. Standard Mesh Size	Size Range (Microns)	Heat L-539	Heat L-540
+80	Greater than 177	0.00	0.00
-80 +100	149-177	0.02	0.02
-100 +140	105-149	0.06	0.08
-140 +200	74-105	17.51	25.90
-200 +270	53-74	27.27	34.28
-270 +325	44-53	10.77	10.45
-325	Less than 44	44.37	29.29

TABLE X

PHYSICAL PROPERTIES OF KELSEY-HAYES RENE' 95 POWDER HEATS

Property	Heat L-539	Heat L-540
Apparent Density (25 cc)	0.145 lb/in^3 (4.02 g/cc)	0.139 lb/in^3 (3.86 g/cc)
Tap Density (100 g sample)	0.172 lb/in^3 (4.02 g/cc)	0.167 lb/in^3 (4.63 g/cc)
Flow Rate (50 g sample)	16.0 sec.	16.0 sec.
0_2 Analysis	110 ppm	121 ppm

PLANS FOR THE NEXT REPORTING PERIOD

The following work is planned to be completed during the next reporting period ending January 31, 1979.

1200° F ALLOY/PROCESS DEVELOPMENT

- Complete evaluation of HIP and heat treatment study of Rene' 95 (Compaction Parameter Study)
- Helium atomize Rene' 95
- Argon atomize and HIP the ten 1200° F Series I alloys

1400° F ALLOY/PROCESS DEVELOPMENT

- Characterize microstructure of two argon-atomized powder heats of Rene' 95.
- Initiate tensile and low cycle fatigue evaluation of Rene' 95 disks.

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